

IMPRINT LITHOGRAPHY TEMPLATE HAVING OPAQUE ALIGNMENT MARKS

BACKGROUND OF THE INVENTION

[0001] The field of invention relates generally to imprint lithography. More particularly, the present invention is directed to producing templates having alignment marks formed thereon.

[0002] Micro-fabrication involves the fabrication of very small structures, e.g., having features on the order of micro-meters or smaller. One area in which micro-fabrication has had a sizeable impact is in the processing of integrated circuits. As the semiconductor processing industry continues to strive for larger production yields while increasing the circuits per unit area formed on a substrate, micro-fabrication becomes increasingly important. Micro-fabrication provides greater process control while allowing increased reduction of the minimum feature dimension of the structures formed. Other areas of development in which micro-fabrication has been employed include biotechnology, optical technology, mechanical systems and the like.

[0003] An exemplary micro-fabrication technique is shown in United States patent number 6,334,960 to Willson et al. Willson et al. disclose a method of forming a relief image in a structure. The method includes providing a substrate having a transfer layer. The transfer layer is covered with a polymerizable fluid composition. A mold makes mechanical contact with the polymerizable fluid. The mold includes a relief structure, and the polymerizable fluid composition fills the relief structure. The polymerizable fluid composition is then subjected to conditions to solidify

and polymerize the same, forming a solidified polymeric material on the transfer layer that contains a relief structure complimentary to that of the mold. The mold is then separated from the solid polymeric material such that a replica of the relief structure in the mold is formed in the solidified polymeric material. The transfer layer and the solidified polymeric material are subjected to an environment to selectively etch the transfer layer relative to the solidified polymeric material such that a relief image is formed in the transfer layer. The time required and the minimum feature dimension provided by this technique are dependent upon, *inter alia*, the composition of the polymerizable material.

[0004] United States patent number 5,772,905 to Chou discloses a lithographic method and an apparatus for creating ultra-fine (sub-25 nm) patterns in a thin film coated on a substrate in which a mold having at least one protruding feature is pressed into a thin film carried on a substrate. The protruding feature in the mold creates a recess of the thin film. The mold is removed from the film. The thin film then is processed such that the thin film in the recess is removed exposing the underlying substrate. Thus, patterns in the mold are replaced in the thin film, completing the lithography. The patterns in the thin film will be, in subsequent processes, reproduced in the substrate or in another material which is added onto the substrate.

[0005] Yet another imprint lithography technique is disclosed by Chou et al. in Ultrafast and Direct Imprint of Nanostructures in Silicon, *Nature*, Vol. 417, pp. 835-837, June 2002, which is referred to as a laser assisted direct imprinting (LADI) process. In this process, a

region of a substrate is made flowable, e.g., liquefied, by heating the region with the laser. After the region has reached a desired viscosity, a mold, having a pattern thereon, is placed in contact with the region. The flowable region conforms to the profile of the pattern and is then cooled, solidifying the pattern into the substrate. A concern with each of the above-identified pattern formation processes relates to proper orientation of the template with the substrate. For example, it is desired to properly align the template with an existing patterned layer so that the proper orientation between the existing patterned layer and a subsequent patterned layer is obtained.

[0006] Thus, a need exists for producing a template having alignment marks for use with imprint lithographic techniques.

SUMMARY OF THE INVENTION

[0007] The present invention is directed to providing a template with alignment marks that are opaque to selective wavelength of light. In one embodiment, a template is provided having patterning areas and a template, with the template mark being formed from metal and disposed outside of the patterning areas. The alignment marks may be surrounded by a moat to prevent curable liquid from being in superimposition therewith during imprinting. In this manner, opaque alignment marks may be employed without degrading the quality of the pattern formed during imprinting. These and other embodiments are discussed more fully below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Fig. 1 is a perspective view of a lithographic system in accordance with the present invention;

[0009] Fig. 2 is a simplified elevation view of a lithographic system shown in Fig. 1;

[0010] Fig. 3 is a simplified representation of material from which an imprinting layer, shown in Fig. 2, is comprised before being polymerized and cross-linked;

[0011] Fig. 4 is a simplified representation of cross-linked polymer material into which the material shown in Fig. 3 is transformed after being subjected to radiation;

[0012] Fig. 5 is a simplified elevation view of a mold spaced-apart from the imprinting layer, shown in Fig. 1, after patterning of the imprinting layer;

[0013] Fig. 6 is a simplified elevation view of an additional imprinting layer positioned atop of the substrate, shown in Fig. 5, after the pattern in the first imprinting layer is transferred therein;

[0014] Fig. 7 is a plan view of an imaging system employed to sense alignment marks;

[0015] Fig. 8 is a plan view of alignment marks employed in accordance with the present invention;

[0016] Fig. 9 is a plan view of alignment marks employed in accordance with an alternate embodiment of the present invention;

[0017] Fig. 10 is a plan view of alignment marks employed in accordance with a second alternate embodiment of the present invention;

[0018] Fig. 11 is a plan view showing alignment marks disposed on a template, shown in Fig. 1;

[0019] Fig. 12 is a plan view of a template showing an arrangement of alignment marks thereon in accordance with an alternate embodiment of the present invention;

[0020] Fig. 13 is a cross-sectional view of the template shown in Fig. 12 taken along lines 13-13;

[0021] Fig. 14 is a plan view of a template showing an arrangement of alignment marks thereon in accordance with a third alternate embodiment of the present invention; and

[0022] Fig. 15 is a plan view of a template showing an arrangement of alignment marks thereon in accordance with a fourth alternate embodiment of the present invention;

DETAILED DESCRIPTION OF THE INVENTION

[0023] Fig. 1 depicts a lithographic system 10 in accordance with one embodiment of the present invention that includes a pair of spaced-apart bridge supports 12 having a bridge 14 and a stage support 16 extending therebetween. Bridge 14 and stage support 16 are spaced-apart. Coupled to bridge 14 is an imprint head 18, which extends from bridge 14 toward stage support 16 and provides movement along the Z-axis. Disposed upon stage support 16 to face imprint head 18 is a motion stage 20. Motion stage 20 is configured to move with respect to stage support 16 along X- and Y-axes. It should be understood that imprint head 18 may provide movement along the X- and Y-axes, as well as the Z-axis, and motion stage 20 may provide movement in the Z-axis, as well as the X- and Y-axes. An exemplary motion stage device is disclosed in United States patent application number 10/194,414, filed July 11, 2002, entitled "Step and Repeat Imprint Lithography Systems," assigned to the assignee of the present invention, and which is incorporated by reference herein in its entirety. A radiation source 22 is coupled to lithographic system 10 to impinge actinic radiation upon motion stage 20. As shown, radiation source 22 is coupled to bridge 14 and

includes a power generator 23 connected to radiation source 22. Operation of lithographic system 10 is typically controlled by a processor 25 that is in data communication therewith.

[0024] Referring to both Figs. 1 and 2, connected to imprint head 18 is a template 26 having a mold 28 thereon. Mold 28 includes a plurality of features defined by a plurality of spaced-apart recessions 28a and protrusions 28b. The plurality of features defines an original pattern that is to be transferred into a substrate 30 positioned on motion stage 20. To that end, imprint head 18 and/or motion stage 20 may vary a distance "d" between mold 28 and substrate 30. In this manner, the features on mold 28 may be imprinted into a flowable region of substrate 30, discussed more fully below. Radiation source 22 is located so that mold 28 is positioned between radiation source 22 and substrate 30. As a result, mold 28 is fabricated from a material that allows it to be substantially transparent to the radiation produced by radiation source 22.

[0025] Referring to both Figs. 2 and 3, a flowable region, such as an imprinting layer 34, is disposed on a portion of a surface 32 that presents a substantially planar profile. A flowable region may be formed using any known technique, such as a hot embossing process disclosed in United States patent number 5,772,905, which is incorporated by reference in its entirety herein, or a laser assisted direct imprinting (LADI) process of the type described by Chou et al. in Ultrafast and Direct Imprint of Nanostructures in Silicon, *Nature*, Col. 417, pp. 835-837, June 2002. In the present embodiment, however, a flowable region consists of imprinting layer 34 being deposited as a plurality of spaced-apart

discrete beads 36 of a material 36a on substrate 30, discussed more fully below. An exemplary system for depositing beads 36 is disclosed in United States patent application number 10/191,749, filed July 9, 2002, entitled "System and Method for Dispensing Liquids," and which is assigned to the assignee of the present invention, and which is incorporated by reference in its entirety herein. Imprinting layer 34 is formed from material 36a that may be selectively polymerized and cross-linked to record the original pattern therein, defining a recorded pattern. An exemplary composition for material 36a is disclosed in United States patent application number 10/463,396, filed June 16, 2003 and entitled "Method to Reduce Adhesion Between a Conformable Region and a Pattern of a Mold," which is incorporated by reference in its entirety herein. Material 36a is shown in Fig. 4 as being cross-linked at points 36b, forming a cross-linked polymer material 36c.

[0026] Referring to Figs. 2, 3 and 5, the pattern recorded in imprinting layer 34 is produced, in part, by mechanical contact with mold 28. To that end, distance "d" is reduced to allow imprinting beads 36 to come into mechanical contact with mold 28, spreading beads 36 so as to form imprinting layer 34 with a contiguous formation of material 36a over surface 32. In one embodiment, distance "d" is reduced to allow sub-portions 34a of imprinting layer 34 to ingress into and fill recessions 28a.

[0027] To facilitate filling of recessions 28a, material 36a is provided with the requisite properties to completely fill recessions 28a, while covering surface 32 with a contiguous formation of material 36a. In the present embodiment, sub-portions 34b of imprinting layer

34 in superimposition with protrusions 28b remain after the desired, usually minimum, distance "d", has been reached, leaving sub-portions 34a with a thickness t_1 , and sub-portions 34b with a thickness t_2 . Thicknesses " t_1 " and " t_2 " may be any thickness desired, dependent upon the application. Typically, t_1 is selected so as to be no greater than twice the width u of sub-portions 34a, i.e., $t_1 \leq 2u$, shown more clearly in Fig. 5.

[0028] Referring to Figs. 2, 3 and 4, after a desired distance "d" has been reached, radiation source 22 produces actinic radiation that polymerizes and cross-links material 36a, forming cross-linked polymer material 36c. As a result, the composition of imprinting layer 34 transforms from material 36a to cross-linked polymer material 36c, which is a solid. Specifically, cross-linked polymer material 36c is solidified to provide side 34c of imprinting layer 34 with a shape conforming to a shape of a surface 28c of mold 28, shown more clearly in Fig. 5. After imprinting layer 34 is transformed to consist of cross-linked polymer material 36c, shown in Fig. 4, imprint head 18, shown in Fig. 2, is moved to increase distance "d" so that mold 28 and imprinting layer 34 are spaced-apart.

[0029] Referring to Fig. 5, additional processing may be employed to complete the patterning of substrate 30. For example, substrate 30 and imprinting layer 34 may be etched to transfer the pattern of imprinting layer 34 into substrate 30, providing a patterned surface 32a, shown in Fig. 6. To facilitate etching, the material from which imprinting layer 34 is formed may be varied to define a relative etch rate with respect to substrate 30, as desired. The relative etch rate of imprinting layer

34 to substrate 30 may be in a range of about 1.5:1 to about 100:1.

[0030] Alternatively, or in addition to, imprinting layer 34 may be provided with an etch differential with respect to photo-resist material (not shown) selectively disposed thereon. The photo-resist material (not shown) may be provided to further pattern imprinting layer 34, using known techniques. Any etch process may be employed, dependent upon the etch rate desired and the underlying constituents that form substrate 30 and imprinting layer 34. Exemplary etch processes may include plasma etching, reactive ion etching, chemical wet etching and the like.

[0031] To form an additional imprinting layer, such as a layer 124 atop of surface 32a, correct placement of mold 28 with respect to substrate 30 is important. To that end, overlay alignment schemes may include alignment error measurement and/or alignment error compensation and/or placement error measurement and correction. Placement error, as used herein, generally refers to X-Y positioning errors between a template and a substrate (that is, translation along the X- and/or Y-axis). Placement errors, in one embodiment, are determined and corrected for by using an optical imaging system 40, shown in Fig. 7, to sense alignment marks discussed below with respect to Fig. 8.

[0032] Referring to Fig. 7, optical imaging system 40 includes a light source 42 and an optical train 44 to focus light upon substrate 30. Optical imaging system 40 is configured to focus alignment marks lying in differing focal planes onto a single focal plane, P, wherein an optical sensor 46 may be positioned. As a result, optical train 44 is configured to provide wavelength-

dependent focal lengths. Differing wavelengths of light may be produced in any manner known in the art. For example, a single broadband source of light, shown as a light 48, may produce wavelengths that impinge upon optical train 44. Optical band-pass filters (not shown) may be disposed between the broadband source and the alignment marks (not shown). Alternatively, a plurality of sources of light (not shown) may be employed, each one of which produces distinct wavelengths of light. Light 48 is focused by optical train 44 to impinge upon alignment marks (not shown) at one or more regions, shown as region R_1 and region R_2 . Light reflects from regions R_1 and R_2 , shown as a reflected light 50, and is collected by a collector lens 52. Collection lens 52 focuses all wavelengths of reflected light 50 onto plane P so that optical sensor 46 detects reflected light 50.

[0033] Referring to Figs. 1 and 8, alignment marks may be of many configurations and are arranged in pairs with one of the alignment marks of the pair being disposed on template 26 and the remaining alignment mark being positioned on substrate 30, typically in a previously deposited imprinting layer. For example, alignment marks may include first and second polygonal marks 60 and 62, depicted as squares, but may be any polygonal shape desired. Another configuration for alignment marks are shown as crosses, shown as 64 and 66. Also additional alignment marks may be employed, such as vernier marks 68 and 70, as well as Moiré gratings, shown as 72 and 74.

[0034] Wavelengths are selected to obtain a desired focal length, depending upon the gap between mold 28 and substrate 30. Under each wavelength of light used, each overlay mark may produce two images on the imaging plane. A first polygonal alignment mark 60, using a specific

wavelength of light, presents as a focused image on sensor 46. A second polygonal alignment mark 62, using the same wavelength of light, presents as an out-of-focus image on sensor 46. In order to eliminate each out-of-focus image, several methods may be used.

[0035] Referring to Figs. 7 and 8, in a first method, under illumination with a first wavelength of light, two images may be received by an imaging device, such as sensor 46, sensing first and second polygonal marks 162 and 164. Assuming polygonal mark 162 is focused and polygonal mark 164 is out-of-focus. An image processing technique may be used to remove geometric data corresponding to pixels associated with polygonal mark 164. Thus, the out-of-focus polygonal mark of the substrate mark may be eliminated, leaving only polygonal mark 162. Using the same procedure and a second wavelength of light, polygonal marks 262 and 264 may be sensed by sensor 46. One of the polygonal marks 262 and 264 is not focused by collection lens 52 on sensor 46, shown a polygonal mark 262, but polygonal mark 264 is focused onto sensor 46. As before, geometric data associated with polygonal mark 262 is removed, leaving only geometric data associated with polygonal mark 264. Thereafter, polygonal marks 162 and 264 are superimposed forming alignment marks 265 to ascertain alignment between template and substrate.

[0036] A second method may utilize two coplanar polarizing arrays, shown in Fig. 10, and polarized illumination sources. Alignment marks may include orthogonally polarizing arrays 76. Polarizing arrays 78 are formed on a surface of mold 28 or placed above the surface. Under two polarized illumination sources, only focused images 78 (each corresponding to a distinct

wavelength and polarization) may appear on an imaging plane. Thus, out-of-focus images are filtered out by polarizing arrays 76. An advantage of this method may be that it may not require an image processing technique to eliminate out-of-focus images.

[0037] Referring to Figs. 1 and 11, Moiré pattern based overlay measurement has been used for optical lithography processes. For imprint lithography processes, where two layers of Moiré patterns are not on the same plane but still overlap in the imaging array, acquiring two individual focused images may be difficult to achieve. However, carefully controlling the gap between template 26 and substrate 30 within the depth of focus of the optical measurement tool and without direct contact between template 26 and substrate 30 may allow two layers of Moiré patterns to be simultaneously acquired with minimal focusing problems. It is believed that other standard overlay schemes based on the Moiré patterns may be directly implemented to imprint lithography process.

[0038] Another concern with overlay alignment for imprint lithography processes that employ UV curable liquid materials may be the visibility of the alignment marks. For the overlay placement error measurement, two overlay marks, such as the marks discussed above with respect to Figs. 8, 9 and 10, are employed, referred to collectively as overlay marks 80. However, since it is desirable for template 26 to be transparent to a curing agent, the template overlay marks, in some embodiments, are not opaque lines. Rather, the template overlay marks are topographical features of the template surface. In some embodiments, the overlay marks are made of the same material as the template. In addition, UV curable

liquids may have a refractive index that is similar to the refractive index of the template materials, e.g., quartz. Therefore, when the UV curable liquid fills the gap between template 26 and substrate 30, template overlay marks may become very difficult to recognize. If the template overlay marks are made with an opaque material, e.g., chromium or nickel, the UV curable liquid below the overlay marks may not be properly exposed to the UV light.

[0039] In an embodiment, overlay marks are used on template 26 that are seen by optical imaging system 40 but are opaque to the curing light, e.g., UV light. An embodiment of this approach is illustrated in Fig. 11. Instead of completely opaque lines, overlay marks 80 on the template may be formed of fine polarizing lines 82. For example, suitable fine polarizing lines 82 have a width about $\frac{1}{2}$ to $\frac{1}{4}$ of the wavelength of activating light used as the curing agent. The line width of fine polarizing lines 82 should be small enough so that activating light passing between two lines is diffracted sufficiently to cause curing of all the liquid below the lines. In such an embodiment, the activating light may be polarized according to the polarization of overlay marks 80. Polarizing the activating light provides a relatively uniform exposure to all regions of template 26, including regions having overlay marks 80. Light used to locate overlay marks 80 on template 26 may be broadband light or a specific wavelength that may not cure the liquid material. This light need not be polarized. Fine polarizing lines 82 are substantially opaque to the measuring light, thus making overlay marks 80 visible using established overlay error measuring tools. Fine polarized overlay marks are fabricated on

template 26 using existing techniques, such as electron beam lithography.

[0040] In another embodiment, overlay marks 80 are formed of a different material than template 26. For example, a material selected to form the template overlay marks may be substantially opaque to visible light but transparent to activating light used as the curing agent, e.g., UV light. For example, SiO_x , where x is less than 2, may be used as such a material. In particular, structures formed of SiO_x , where x is about 1.5, are substantially opaque to visible light, but transparent to UV curing light. Alternatively, or in conjunction with the SiO_x , alignment marks may be formed from a metal, i.e., chromium, nickel, and the like. In this manner, alignment marks 80 are opaque to both the analyzing light and the activating light. To ensure that alignment marks 80, such as the metal alignment marks, do not compromise the imprint pattern by, inter alia, blocking the activating light, alignment marks 80 may be positioned outside of the imprinting area, e.g., alignment marks 80 may be positioned in a region in which no features are patterned. To that end, a template 326 includes four molds 328, 330, 332 and 334, each of which has features f_1 , f_2 , f_3 and f_4 , respectively, with alignment marks 80 disposed in a region of template 326 outside of molds 328, 330, 332 and 334.

[0041] Referring to Figs. 12 and 13, to prevent imprinting material (not shown) from entering a region of substrate 30 in superimposition with alignment marks 80, alignment marks 80 are surrounded by a moat system 336. This is important as the opaqueness of alignment marks 1302 formed from metal would hinder, if not prevent, solidification of curable liquid. Segments 336a, 336b,

336c and 336d of moat system 336 separate molds 328, 330, 332 and 334. Specifically, segments 336a, 336b, 336c and 336d have a sufficient depth to curable liquid from substantially egressing therein from adjacent active molds 328, 330, 332 and 334 due to capillary forces. Additionally, moat system 336 may include a segment 336e that surrounds molds 328, 330, 332 and 334.

[0042] Referring to Fig. 14 in another embodiment, alignment marks 80 may be placed within a mold, shown as a mold 428. However, the region of mold 428 in which alignment marks 80 are positioned does not include any patterned features. Alignment marks 80 are surrounded by moat 436 so as to prevent liquid imprinting material from coming into contact therewith for the reasons discussed above with respect to Figs. 11 and 12. Alternatively, an additional set of alignment marks may be included in a region outside of molds 428, 330, 332, 334, shown as alignment marks 180. Additionally, alignment marks 280 and 282 may be disposed at opposite corners of a mold, such as a template 528 shown in Fig. 15. Alignment marks 280 and 282 may or may not be surrounded by a moat to prevent liquid imprinting material from coming into contact therewith, as discussed above with respect to moat 436 in Fig. 14. Additionally, it has been found desirable to have at least one of alignment marks 280 and 282 not surrounded by a moat and not formed from opaque material.

[0043] From the foregoing, it is seen that alignment marks 80 formed from metal may be employed without degrading the underlying pattern generated during imprinting. Employing metal alignment marks may reduce the processing time required when manufacturing template 326. For example, template 326 may be patterned with

features f1, f2, f3, and f4, as well as alignment marks 80 using e-beam lithography. As is well known, chromium or some other metals is employed as masking material during e-beam patterning processes. Arranging alignment marks 80 as discussed above would enable leaving masking metals in the region of alignment marks 80 after e-beam patterning.

[0044] The embodiments of the present invention described above are exemplary. Many changes and modifications may be made to the disclosure recited above, while remaining within the scope of the invention. Therefore, the scope of the invention should not be limited by the above description, but instead should be determined with reference to the appended claims along with their full scope of equivalents.